USGS

WATER RESOURCES RESEARCH GRANT PROPOSAL

Title: Hyperfiltration-Induced Precipitation of Sodium Chloride.

Priority Problem Area: Utilization of saline and other impaired waters.

Focus Category: Wastewater, Treatment.

Keywords: Membrane, Reverse Osmosis, Waste Reduction, Hyperfiltration, Precipitation, clay membrane.

Duration: 14 months; Start May 1, 1999; End June 30, 2000

1999 WRRI Award: Total: $51,135

Federal: $ 23,200

Non-federal: $27,935

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Congressional District Number: 1

Statement of the Critical Water Resource Problem

Conventional reverse osmosis shows great promise of providing an economical method of purifying saline and other impaired waters. However, reverse osmosis is presently limited by a relatively large waste stream which, for some applications, can be as much as 80% of the total volume treated. High waste disposal costs rule out or severely limit the use of reverse osmosis for many applications. The goal of this project is to reduce the reverse osmosis waste stream to a solid¾a reduction in waste volume of up to four orders of magnitude-thus allowing all of the water input into the system to be purified. In a previous WRRI-funded project (Whitworth and DeRosa, 1997), heavy metals including copper, cobalt, and lead, were successfully precipitated from initially undersaturated chloride solutions forced through clay membranes (hyperfiltration). Metal chloride solutions are quite soluble, but not as soluble as sodium chloride; a common constituent of almost all waters. If this waste reduction system is to be widely applicable, it must be able to precipitate highly soluble dissolved minerals such as sodium chloride as well as less soluble dissolved minerals. Theoretical calculations suggest that it is not only possible to precipitate sodium chloride from an initially undersaturated solution passing through a membrane, but that it can be done at fluid pressures of less than 400 psi-pressures significantly less than those used in most reverse osmosis systems. The secret is in the use of an osmotically inefficient membrane. Clay membranes will be used in the proposed experiments because their osmotic efficiency is related to membrane compaction, which is simple to control experimentally. Potential uses of the reverse osmosis waste reduction system important to New Mexico include treatment of irrigation water to reduce total dissolved solids (TDS), treatment of river water to reduce TDS, utilization of saline and other impaired waters by both municipalities and individuals, and remediation of impaired waters.

Statement of the results, Benefits Expected

The objectives of this project are to 1) experimentally demonstrate that hyperfiltration-induced precipitation of sodium chloride can occur, and 2) conduct bench-scale testing using this process to reduce reverse osmosis waste to a solid. This reverse osmosis waste reduction system will significantly cut waste disposal costs. For example, calculations show that, if this waste reduction system is added to a conventional reverse osmosis unit which treats 2000 mg/l water to 250 mg/l total dissolved solids with a waste stream of 30%, the waste disposal costs (based on weight) will be only 5.8% of normal. For a conventional reverse osmosis system treating 20,000 mg/l water to 250 mg/l, with a waste stream of 80% the total volume, the waste reduction system can reduce waste disposal costs to 2.5% of normal.

The ultimate goal of this research is to improve the commercial viability of this method so that industrial partners can be attracted to make this process available to users in New Mexico and the rest of the world. This waste reduction process will make it possible to design compact, point-of-use reverse osmosis systems which use sealed disposable waste cartridges as well as much more efficient and cost-effective, large-scale reverse osmosis desalination systems.

An important design criteria for membrane systems is to maximize the membrane area per system unit volume. Commercial reverse osmosis systems use spiral-wound membranes in which the membrane is sandwiched between two mesh spacers and wound into a cylindrical bundle to maximize membrane area. A similar approach could be taken with clay membranes, however removing precipitate from spiral-wound systems would be awkward. Perhaps a better approach is to use tubular ceramic membranes. For example, 778-3/8 inch diameter tubular ceramic membranes could be packed into a pipe with a 12 inch internal diameter. The ends of the tubes could all be capped with high strength, injection-molded, one-piece plastic caps that would seal both the ends of the tubular membranes and the ends of the outer cylinder. This arrangement would yield 14,665 square inches of membrane in a one-foot long cylinder. The wastewater would enter each tubular membrane through one end cap, and the effluent would be retained by the outer cylinder, where it could be removed through one or more ports. This design has the following advantages: 1) ceramic membranes are cheap to mass produce and are long lasting, 2) ceramic membranes are strong and can handle high pressures, 3) if one or more tubular membranes break within the outer cylinder, they can be individually plugged off or replaced so that the entire unit does not need to be replaced, 4) the system has simple plumbing, 5) the system can be easily flushed of precipitate and/or acid treated as necessary.

Further funding will be sought for this next step in the project after this segment of the work is completed. Experimental proof that sodium chloride can be precipitated from initially undersaturated solutions during hyperfiltration is necessary to attract future funding to develop this reverse osmosis waste reduction system. Funding to continue this work will be sought from private industry, as well as the U. S. Department of Energy.

Nature, Scope and Objectives

Less than two percent of the world's water supply is fresh water suitable for drinking (Fetter, 1988). The rest is too saline for human consumption (i. e., total dissolved solids greater than 1000 mg/l). Therefore, as world population grows, especially in arid or semiarid areas, fresh water supplies are often being used up faster than they can be naturally replaced. This is currently the situation in the city of Albuquerque, where groundwater levels are dropping every year and conservation measures are being implemented. It is increasingly important that cost-effective methods be developed for use of saline or other impaired waters in order to ensure adequate future water supplies for the people of the state of New Mexico, as well as the rest of the world.

Large volumes of saline waters underlie about two-thirds of the continental United States, including New Mexico (Feth, 1970). Few aquifers in New Mexico contain only fresh water. Most also contain significant volumes of saline water, often at relatively shallow depths (Hood and Kister, 1962).

Conventional reverse osmosis shows promise of providing an economical method of purifying saline and other impaired waters. However, a major limitation is its relatively large waste stream. For some applications this waste stream can be as much as 80% of the total volume treated. High waste disposal costs rule out or severely limit the use of reverse osmosis for many applications. The goal of this project is to reduce that waste stream to a solid¾a reduction in waste volume of up to four orders of magnitude-thus allowing all of the water input into the system to be purified. The P.I., in cooperation with the New Mexico Tech Research Foundation, has applied for a patent on a process that promises to accomplish this goal . In a previous WRRI-funded project (Whitworth and DeRosa, 1997), we successfully precipitated heavy metals including copper, cobalt, and lead, from undersaturated chloride solutions passed through clay membranes. The patent application uses the P.I.'s method of precipitating solutes to reduce the waste stream volume from conventional cross-flow reverse osmosis systems.

Metal chlorides, such as $CuCl_2$, $PbCl_2$, and $CoCl_2$, are quite soluble (with solubilities ranging from 5.7×10^{-5} to 3.47 molar), but not as soluble as sodium chloride (solubility 6.2 molar). Sodium chloride is the most common constituent of saline waters and is the only constituent of natural waters in which concentrations commonly exceed 20,000 mg/l (Feth, 1970). If a reverse osmosis waste reduction system is to be widely applicable, it must be able to precipitate highly soluble dissolved minerals such as sodium chloride as well as less soluble dissolved minerals. Theoretical calculations suggest that, it is not only possible to precipitate sodium chloride from an initially undersaturated solution passing through a membrane, but that it can be done at fluid pressures of less than 400 psi-pressures significantly less than those used in most reverse osmosis systems. The calculations follow in a later section.

The secret to hyperfiltration-induced precipitation of highly soluble minerals such as sodium chloride at such low pressures is through the use of an osmotically inefficient membrane. Clay membranes will be used in the experiments because their osmotic efficiency is related to the amount of compaction, which is simple to control in the experiments.

Potential uses of the reverse osmosis-membrane waste reduction system important to New Mexico include treatment of irrigation water to reduce total dissolved solids (TDS), treatment of river water to reduce TDS, utilization of saline and other impaired waters by both municipalities and individuals, and remediation of impaired waters.